

Strategic Management via System Dynamics Simulation Models

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Abstract—This paper examines the problem of strategic management in highly turbulent dynamic business environmental conditions. As shown the high complexity of the problem can be managed with the use of System Dynamics Models and Computer Simulation in obtaining insights, and thorough understanding of the interdependencies between the organizational structure and the business environmental elements, so that effective product –market strategies can be designed. Simulation reveals the underlying forces that hold together the structure of an organizational system in relation to its environment. Such knowledge will contribute to the avoidance of fundamental planning errors and enable appropriate proactive well focused action.

Keywords—Strategic Management, System Dynamics, Modeling and Simulation, Strategic Planning, Organizational Dynamics

I. INTRODUCTION

THE high complexity of organizations and their changing environment calls for new approaches to Strategic Management. It seems that the famous quote of the ancient greek philosopher Heraklitus “you cannot step in the same river twice” is more true today than ever. Not only organizations should be prepared for sudden storms that turn the calm waters of the river into wavy water rapids, but the stormy and turbulent conditions are the norm of today’s business competitive environment. Moreover, the recent world financial crisis reinforces this highly uncertain problematic situation as it has a direct effect on the bottom line for the cost of operations. The plain fact is that today’s organizations are called to develop flawless and absolutely effective strategies in order to survive and prosper in a highly competitive marketplace. There is no room for mistakes and real life experimentation when it comes to making business decisions.

However, as environmental conditions change, at the same time new opportunities are created. Especially, the recent advancement in information technology and the capability for cost effective computer business modeling and simulation, opens up new ways for experimenting with business decisions by testing a number of alternative plausible strategies in a controlled computer simulated environment. With the exploitation of transistor technology in the past and parallel

processing at present, computers are becoming smaller, cheaper, more powerful and easier to use by even non-computer specialists. Modern portable computers allow the analyst to explore a whole range of options in a decision problem. The ultimate way in which today’s management scientist should use a computer is to simulate the system under investigation using computer experimentation. In such simulations a computer is used for its ability and speed in mimicking the behavior of the system under study over a period of time. In this way a framework platform is created for carrying out scientific experiments that test organizational strategies prior to implementation.

As seen in the following sections the plans are drawn for such a strategic framework and the mechanisms that need to be in place to make it work, are identified. Section II explains the idea of holism in relation to organization systems. Next, section III reviews computer simulation in relation to strategic management followed by section IV which explains the system dynamics paradigm, which acts as the engine of the strategic framework platform. Section V presents the Strategic framework platform which is applied in a particular case study. Finally section VI draws the main conclusions and future work in the area.

II. THE HOLISTIC NATURE OF ORGANIZATIONAL SYSTEMS

The role of management today has shifted from managing individuals to managing teams or human activity social systems. A profound implication of this is that the research methodology that uses rigid algorithms for filtering data into factors or applies multiple regression formulas for assessing how dependent and independent variables co-vary in an attempt to "rigorously" quantify complexity, has only a limited problem solving capacity. The reason for this limitation is that social systems are essentially goal-seeking information feedback systems. Thus, models of such systems need to be models of holistic view to the organizational system, not merely of isolated components of an information feedback loop.

By taking a "snap shot" picture in time and by separately examining changes of a variable along short routes on the information feedback loop, we cannot expect to derive the behavior of the whole. Models of such systems must preserve the closed loop structure that creates the interesting behavior.

The biggest concern of management today is to reconcile and balance up complexity between an organization as a

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system and its environment. The bulk, if not the whole, of the responsibility for fulfilling this outstanding task falls on the function of strategic management.

The solution to this problem lies on two components:

- the organizational structure of the system
- the "steering" possibilities that this structure allows

Thus, regulating the complexity in strategic management can be achieved through redesigning the organizational system structure on the one hand and through problem solving or decision making on the other. The ability of the system to absorb its environmental complexity is determined by its structure. There are structures that improve the manageability of the system and others that reduce it. Thus, identifying favorable or unfavorable structures and capable of performing at the required level, becomes a primary task.

Further, strategies developed without considering the possible behavioral aspect of organizational reality are doomed to fail. Hence, structure must be linked with behavior if we want to understand the organizational system and its pathological characteristics. As a result, we will be able to redesign the structure or develop strategies that can absorb the variety of differences between the organizational system and the business environment.

Then the need for a framework where we can base our diagnosis imminently arises. Organizational structure is not just an arrangement of independent static elements. There are also unobservable forces leading to the creation of that order we are able to identify as structure. These forces hold together, at least temporarily, the structural order. Taking the paradigm of Research in engineering systems, it should be possible to identify many of these forces and thereby to design and construct successful systems sometimes through observations, but mainly through experimentation. In the social sciences field the forces that hold the system together are more difficult to identify, but that does not mean they do not exist.

Beer (1972) [1], suggest the development of the non-pathogenic structure of the Viable System Model. Two types of order according to Beer, cosmos and order, are integrated and manifest themselves in the Viable System Model, which thus can serve our diagnostic and design purposes to a great extent. The structure of the Viable System Model is today thoroughly explained, methodologically documented in protocols and techniques and widely applied with empirically supported results and stories of success in numerous situations.

Complexity balancing can also be achieved through problem solving. In fact, problem solving and system structure combine their forces to solve the problems of strategic management.

Both tools, that is the Viable System Model and general decision making, are combined to solve both, diagnostic and design problems, which in practice, in spite of the separation we undertake for convenience, they are not so clearly detached. We cannot deal with the problems of one group without considering the other.

Linking structure to behavior for the purpose of intelligent steering, forces us to distinguish between the object-level, that

is the one producing the observable behavior, and the meta-level, that is, "the hidden forces" or decision rules steering the object system. These rules belong, in a logical form, to a meta-level to the object system. These rules or patterns, which take the visible form of possible "bandwidths" of values of variables in interaction within a system, are the ones used in engineering research studies, which enable the design of new systems, capable of performing a given task. Thus we need a methodology in strategic management that quantifies - measures the output of the interaction between the object-system and the environment. In this way the meta-system level will develop learning capabilities of the pattern of interactions. The strategic management methodology has to be rigorous, otherwise, converting the information into rules for viability at the meta-level will not be successful. Meta-systemic steering can only work with a model that enables the analysis of the object system from the point of view of its meta-system with meta-systemic instruments.

In order to increase our diagnostic capability we should apply a holistic systems methodology. There are two widely different approaches to choose from. The analytic-objectivistic methodology manifesting itself in the econometric paradigm, and the systemic-evolutionary or cybernetic method manifested in the system dynamics paradigm. Both are necessary, because strategic problems could be both static and dynamic in nature, points of time and with varying dynamic characteristics. Thus, the methodologies have to be integrated if we seriously want to increase our understanding of socio-technical organizational systems.

The synthesis is absolutely necessary for strategic management. The strategist would need both approaches, for short-term realistic predictions which is the outcome of the econometric modeling paradigm as well as for long-system changes, which is the outcome of the system dynamics modeling paradigm. Only then can strategic management effectively, proactively cope with the rapid changes in the business environment, by the creation of an homeostatic dynamic organizational system.

Strategic management has the task of successfully positioning the organizational system as a whole in a rapidly changing business environment. During this process the organizational system itself is changing as well, either as a result of external forces or through internal forces. We thus need to understand both structural organizational and business environmental forces. Any serious attempt for problem solving should take into account these forces. The suggestions for dealing with the dynamic nature of strategic decision making, is presented in the following sections.

III. COMPUTER SIMULATION AND STRATEGIC MANAGEMENT

Computer simulation methods have been developed since the early 1960s and may well be the most common of analytical tools of management science. The basic principle of computer simulation modeling is that the analyst builds a model of the system of interest using a suitable software

package and then uses computer simulation to generate the system's behavior when subject to a variety of policies, with the purpose of selecting the most desirable policy.

Computer modeling of social and economic systems has been used to analyze everything from inventory management in corporation to the performance of national economies and to the interplay of global population, resources, food, and pollution. Particular computer models such as *The Limits to Growth* (Meadows et al, 1972) [2], are still making front page news especially in relation to environmental concerns.

The usefulness of these simulation models could even explain very significant phenomena such as the recent world financial crisis. Many experts around the world came to the realization the current economic model is not sustainable and a new model of capitalism that would shift from continuous economic growth to a steady state system is more viable. Specifically as Dale [3] suggest in order for people to wake up in this new economic reality will require something like repentance and conversion.

Computer model creation and simulation is the means for studying complex phenomena today. A model though is a substitute for some real problem situation or a system. As such, models are necessarily simplifications and abstractions to some degree of the reality of the problem situation. As John Sterman aptly stated all models are wrong (Sterman, 2002) [4], a statement which is the closest to truth that one can get. Very recently, even Einstein's relativity theory was put into question when material particles at Cern [5], were observed to travel faster than the speed of light. That of course does not mean that Einstein's theory was or it is useless today. Successful models should rather be assessed on their usefulness and appropriateness to deal with the problem situation under study and not on their ability to accurately depict reality. It is neither feasible nor possible to examine all the variables or all their possible interactions in the problem situation.

Therefore, the analyst should attempt to distill the important elements of the problem situation and represent them so that they are simple enough to be understood and utilized, yet realistic enough to portray the essentials of the situation. In this way, the value of a model emerges from its improving our understanding of obscured behavior characteristics more effectively than could be done by observing the real system. Like this, a model compared to the real system, can yield information at a lower cost, while knowledge can be obtained more quickly and for conditions not easily observable in real life.

Before we examine System Dynamics (SD) as the proposed modeling methodology (see the next section), a brief discussion of model validation becomes necessary at this point: Model validation is an important aspect of any model-based methodology in general and the System Dynamics methodology in particular. Most of the literature in SD model building and validation revolves around the notion that a SD continuous simulation model constitutes a theory about how a system actually works. SD models claim to be causal ones and

as such, are used to generate information and insights for diagnosis and policy design, theory testing or simply learning. Therefore, there has to be a strong connection between how theories are accepted or refuted in science, which is a major epistemological and philosophical issue, and how system dynamics models are validated. Barlas and Carpenter (1992) [6], give a detailed account of this issue comparing the two major opposing streams of philosophies of science and convincingly showing that the philosophy of system dynamics model validation is in agreement with the relativistic/holistic philosophy of science.

For the traditional reductionistic/logical empiricist philosophy (underlying for example econometrics), a valid model is an objective representation of the real system. The model is compared to the empirical facts and can be either correct or false. In this philosophy validity is seen as a matter of formal accuracy, not practical use. In contrast, the more recent relativist/holistic philosophy would see a valid model as one of many ways to describe a real situation, connected to a particular purpose. Models, are not necessarily true or false, but suitable or unsuitable for their purpose. In this sense, validation is an evolutionary process of social conversation for building confidence in the usefulness of the model with respect to its purpose. This is also very well demonstrated by (Hadjis and Papageorgiou, 2006) [7], in *Combining Relativism with Logic and Empirical Knowledge for Formulating Effective Strategies*.

IV. SYSTEM DYNAMICS AS MODELING AND STRATEGIC PLANNING TOOL

System dynamics was developed at MIT during the 1950's, mainly by Jay W. Forrester, a control engineer and computer scientist. By combining ideas from three fields, then relatively new, Forrester developed a guiding philosophy and a set of techniques for simulating complex, non-linear, multi-loop feedback systems. The ideas originally combined were brought together from control engineering that is, the concepts of feedback and system self-regulation, cybernetics that is, the nature of information and its role in control systems, and organizational theory, that is the structure of human organizations and mechanisms of human decision making, (Meadows, 1985) [8].

If econometricians see the world as a collection of economic variables contained in statistical data bases, the system dynamics strategist sees it as a conglomeration of interacting feedback loops that generate the nature of the dynamic characteristics that are of interest.

The primary assumption of the system dynamics paradigm is that the persistent dynamic tendencies of any complex social system arise from its internal causal structure. Thus, if a model is to indicate the effect of real system changes, there must be a correspondence between the parameters and structure that could be changed in the system, and the parameters and structure of the real system.

The mechanisms of the model must represent mechanisms

of the real system, so that the model is capable of generating the direction of the major changes in system performance. In this case, performance is not taken to mean the prediction of the future system state and the exact numerical values of variables, but generating the behavior of patterns and dynamic tendencies, such as stable or unstable, oscillating, exponentially growing, self-correcting or in equilibrium. For instance, a system dynamics strategist will rather be interested in profitability and cash level significant variations than the exact numerical values of a projected cash flow. The strategist should be interested in the pattern of company growth whether that is growing oscillating or declining, etc., and the degree of market penetration and not necessarily the exact market share of the company at a future point in time. In general, the strategist should be interested in those characteristics, belonging to a meta-logical level that is meta to the operating system level, which indicate the desirability of system states projected by a simulation.

The central idea that system dynamics uses to understand system structure is the two-way causation or feedback. It is assumed that social or individual decisions are made on the basis of information about the state of the system or the environment surrounding the decision-maker. The decisions lead to actions that are intended to change an undesirable outcome or maintain the desirable state of the system. New information about the system state then produces further decisions and changes. The process is continuous and each such closed chain of causal relationships forms a feedback loop. By definition then, system dynamics models are made up of many such loops linked together, and are basically closed-system representations in which most of the variables occur in feedback relationships and are endogenous.

The system dynamics strategist recognizes that noise, that is random events whose source is outside the real system represented, such as the uncertain influence of weather, local, national or international political news, measurement error etc., can take an unpredictable form and have unknown influences when compared with orderly forces, like observed regular time-series. Thus every business decision has a noise uncertainty component. By definition the exact time pattern of this noise is completely unknown or there exist useful estimates of its magnitude and statistical characteristics. In system dynamics the model could receive the noise components as it could receive all other flows within the system. The structure and characteristic of the model determine the nature of the reaction to the noise. Not knowing the instantaneous values of noise, does not obscure the study of the kind of behavior exhibited by the system, including the sensitivity to the noise inputs (Forrester, 1969) [9]. This sensitivity can be experimentally established by changing the noise random seeds for simulation of the model.

Concerning feedback processes, these do not operate instantly, but rather the timing of system behavior depends on elements that create inertia or delays. Thus, information about action is not immediately available. Decisions do not respond

instantaneously to available information and time is required for executing actions indicated by a decision. These accumulations or inertial elements that describe the state of the system when every activity stops, are referred to as levels or stocks, and they can be material form or information. Typical material levels are capital stock, inventories, cash balances. Levels of information can be perceptions like quality indices, or knowledge and cumulative learning. In enabling and inhibiting actions, levels function both as resources and constraints.

System elements representing the decision, action, or change in a level are called rates. A rate is a flow of material or information to or from a level. Examples are investment rates, rates of hiring, rates of potential customers becoming interested, etc. Rates define the present instantaneous flows between the levels of the system. They correspond to activities, while the levels measure the resulting state to which the system has been brought by the activity. The rates of flow are determined by the levels of the system according to rules defined by the decision functions. In turn, the rates determine the levels. The levels determining a particular flow rate will usually include the level from which the flow itself comes.

The representation of a system by means of feedback, levels and rates requires a careful distinction between stocks and flows of real physical quantities and of information. In the system dynamics paradigm physical flows are constrained to obey physical laws such as conservation of mass and energy. On the other hand, information does not need to be conserved, it may be at more than one place at the same time, it cannot be acted upon at the moment of its generation and it may be biased, delayed, amplified or attenuated. Since information is the raw material of decisions, information distraction must be included in the model, if we are to represent decisions properly. The principle of independence of decisions, applicable in practice, makes possible a formulation that is free of simultaneous algebraic equations.

Two kinds of feedback loops are distinguished by the system dynamics strategist: Positive loops which tend to amplify any disturbance and to produce exponential growth, and negative loops that tend to negate any disturbance and to move the system towards an equilibrium point or goal. Combinations of these two kinds of loops appear very frequently and allow strategists to formulate a number of useful theorems connecting the structure of a system that is, the pattern of interconnected interacting feedback loops to the system's dynamic behavioral tendencies, ranging from exponential growth to oscillatory or sigmoid patterns (Gomez, 1981) [10].

This simple realization has recently led SD researchers to isolate and describe generic structures, invariably appearing in many management contexts such as (Senge, 1990) [11] with the concept of the learning organization, (Sterman 2000) [4] with business dynamics, (Morecroft, 2007) [12] by viewing Strategic modelling and business dynamics as a feedback systems approach. Further, Kim Warren [13,14,15] is actually

using system dynamics modeling and simulation to teach Strategic Management at London Business School.

The various business dynamics models, permit identification of isomorphism in very different systems that can be expected to have similar behavioral patterns. For example, stock and flow will exhibit the same exponential growth pattern in a system depicting accumulation of customers as customer behavior is modeled using various parameters. Time delays can be crucial determinants of the dynamic behavior of a system. System dynamics emphasizes the consequences of different lagged relationships in real systems and modelers search carefully for such lags.

Non-linearities can cause feedback loops to vary in strength, depending on the state of the rest of the system. Linked non-linear feedback loops thus form patterns of shifting loops dominance that generate most of the observable behavior, making their proper identification a necessary prerequisite for understanding how a system works.

V. THE PROPOSED STRATEGIC MANAGEMENT FRAMEWORK

The proposed approach to strategic management is concerned with understanding and managing strategic decisions through time. The responsibility of managers and policy makers of governmental agencies should be to improve their organization's competitive position through making the right decisions at right moments in time. To fulfill this responsibility, management should at all times be able to determine why its competitiveness level is at the current position, what would the competitiveness level be in the future with the current strategies employed, and what strategies would improve competitiveness.

A dynamic approach to strategic management is necessary which takes into consideration that businesses are invariably subjected to unpredictable disturbances originating from multiple sources. The approach incorporates control theory which utilizes methods techniques and tools in order to lead a dynamic process towards a desired objective. Monitoring would be essential to ensure that the desired goal is eventually reached or maintained. This kind of monitoring is known as feedback control in "system dynamics" terms.

Strategic management can therefore be modelled as a system dynamics control problem, which could be represented by an entity that transforms inputs into outputs e.g. businesses makes use of resources to increase profitability or customer satisfaction, a target e.g. desired level of profitability or customer satisfaction, controls e.g. adjusting the level of resources and other factors used to profitability or customer satisfaction, monitoring e.g. projected levels of profitability and other variables as compared with the target, external forces that influence the behaviour of the entity, e.g. recession in the environment.

In order to capture the behaviour of the organizational strategic management system the model created should include mathematical expressions that describe the behaviour of the organisational/environmental system over time and its

response to control inputs. Appropriate strategies would then be important decisions that drive the system towards the desired goal.

Since many of today's strategic problems are transient in nature – i.e, market development, new product introductions, capacity additions, etc – a dynamic model should be able to describe these one-time phenomena changing the character of the system. The way is through simulation. A strategic management dynamic model is capable of simulation and hence enables controlled experimentation. This means that such models should be of an abstract mathematical nature. A mathematical model is more specific than a verbal model. It is less ambiguous, it can be more easily managed, through experimentation and it can be more readily used to trace assumptions to their resulting consequences, capturing so the dynamics of time-varying and non-linearity, which characterized activities in social systems.

Mathematical models in the social sciences cannot be the same as the simple models of physical sciences, because physical science models have been deduced from phenomena that can be observed, but usually not altered. Linear analysis is in this case applicable and satisfactory for the rather explanatory character of these models. However, in social systems, we can significantly alter the phenomena, thus a model is also used for designing new systems.

The last realization puts the issue of validity under a new light: strategic management dynamic models are not necessarily correct or false. They are models to substitute our mental models for the real system. Thus, validity of such a model should be a matter of agreed utility and usefulness, decided by the objectives of those involved. We may conclude that different attitudes towards data and their accuracy will only be determined by the different objectives ascribed to the models.

In real practice the manager deals continuously with mental and verbal abstract models of the firm. All the participants have their assumptions about how things work around the firm. There are many, frequently not coinciding descriptions of activities. How do we then incorporate any sort of discipline into the process of building the model, so that the resulting planning platform is solid and not anybody's guess? We return, in other words, to the methodological aspects of the proposed integration. The solution to this problem can be found in two steps. First, the process is one of translating an implicit informal thought model of the people involved into a formal verbal model with explicit clear statements. The reason is that we always begin a modeling process with a verbal model of descriptions and conversation. The second step is to translate the now formal verbal problem into a mathematical model.

The first step of converting the existing individual-idiosyncratic thought-model into one with clear statements is rather difficult. It is at this point that inaccurate statements can creep in. The problems of going from the verbal to the mathematical statements arise when the initial verbal model is not an adequate description of the system under study.

Structural configurations are in a continuous interaction. This invalidates any static perspective and forces us to link structure to behavior in a dynamic system of continuous interaction between the important structural variables. In this way we may construct and study satisfactory approximations of the real system's path over time.

The application of the proposed strategic management method was carried out as part of a case study regarding a Strategic Business Unit of a large German company active in the field of software development. As a starting point of our modeling effort the advantages of using System Dynamics were explained to the management team, after which the approval for going ahead with the project was obtained. Methodological aspects, resulting from our previous discussion were taken into account in developing the proposed modeling method. During the experiment our main concern was to verify if the expected synergistic effects and complementary strengths of System Dynamics really exist, and if they were capable of widening the scope and enhancing the effectiveness of strategic decisions. The iterative nature of the process unfolded in two workshops, stretching over a period of two months, because of time constraints of the team's members. The main parts of the model were constructed during the workshops. Guided tests and simulations were also prepared. As every step undertaken was thoroughly explained and approved by the team, we see no methodological difference between the path followed and the one that could have been followed without our presence, if the team were sufficiently trained in the use of the software, and another coordinator undertook the role. The criteria and heuristics, extracted throughout this work, were applied and tested. The team members were in a position to undertake the modeling effort and test business scenarios for the purpose of developing effective strategies.

Therefore a dynamic approach to the strategic management process allows top managers to find answers to questions related strategy effectiveness under a variety of alternative business scenarios. Particularly, specific marketing initiatives for awakening customer awareness could be identified, ideas could be generated of how to stir up demand with the different policies, discovery could also occur of what would be the best strategies to stimulate growth and so on. In turn validated simulation experiments can verify answers to the above questions with a specific degree of certainty. Further, sensitivity analysis can provide a deep understanding of the business environment structure and behavior of future scenarios may be modeled.

VI. CONCLUSIONS

This paper examined the use of computer simulation based approach for developing effective organizational strategies. The complexity and uncertainty of the organizational environment and the continuous change which is manifested in new business models and new value systems makes it impossible for the intuitive human mind alone to respond with

developing effective strategies. Further, current strategy analysis techniques use a rather static approach which contradicts the unremitting changes that occur in the competitive landscape on extended time scales. To be more effective in choosing appropriate strategies a more dynamic approach to strategy development is necessary whereby the performance of a firm is projected and steered into the future.

Taking advantage of the rapid changes in computer technology and using the approach of systems thinking and the principles of "system dynamics" computer models of organisations in relation to their environments can be created. The behaviour of the system models can thereby be investigated by testing various business scenarios in a computer simulated controlled environment. Based on this investigative research method of computer simulation and experimentation, plausible strategies can be tested on their effectiveness prior to their implementation. In this way possible mistakes which can prove detrimental to organizations can be avoided. Further, the whole process of building the organizational-environmental model provides significant learning experience for the strategist.

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